Requirements for the Design of a Personal Document-Management System

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Windesheim University of Applied Sciences
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Olha Bondarenko
Eindhoven University of Technology, 5600MB Eindhoven, The Netherlands. E-mail: o.bondarenko@tue.nl

Ruud Janssen
Novay, 7500AN Enschede, The Netherlands. E-mail: ruud.janssen@novay.nl

Samuël Driessen
Océ-Technologies, 5900MA Venlo, The Netherlands. E-mail: samuel.driessen@oce.com

In this article a set of requirements for the design of a personal document management system is presented, based on the results of three research studies (Bondarenko, 2006; Bondarenko & Janssen, 2005; Bondarenko & Janssen, 2009). We propose a framework, based on layers of task decomposition, that helps to understand the needs of information workers with regard to personal document and task management. Relevant user processes are described and requirements for a document-management system are derived for each layer. The derived requirements are compared to related studies, and implications for system design are discussed.

Introduction

In the past, knowledge work involved managing only paper documents. The digital era brought significant changes into the workflow of information workers. First, the amount of available information has increased dramatically with the development of global networks such as the Internet. Currently, there are over 185 million Web sites available for public use (Netcraft, 2009) and this number is growing daily. At the same time, it has become more difficult to determine the value of available information: An increasing number of factors make it complicated to identify the trustworthiness of a source (Bouwhuis, 2006). Second, information exchange has accelerated with the introduction of e-mail and other digital means of exchanging information. The number of digital communication channels has also steadily increased. Starting with e-mail and professional community networks, these communication channels currently include various instant messaging tools, forums, blogs, chat rooms, social-networking tools, Web conferencing, and voice-over-IP. Third, the number of devices and tools that an information worker has to operate has also increased dramatically. At the beginning of the 21st century, the physical workplace of an information worker has acquired its digital counterpart, currently consisting of a variety of devices, from PCs to handheld computers and mobile phones. There is an even bigger variety of software tools, from e-mail clients and office software to dedicated applications for professional use. New devices and new versions of software are frequently released, forcing users to learn tools and acquire new skills, while the number of places where information is stored in a variety of formats continues to increase. Finally, in this digital era paper documents are still widely used. Information workers, therefore, operate in a mixed environment consisting of information on physical and digital carriers.

Although technological progress opens a lot of possibilities for knowledge work and communication, information workers often experience information overload and stress (Kirsh, 2000) as a result of the aforementioned changes. The office environment and ways of working are changing radically, with people working from home, on the way to the workplace, having multiple workplaces, or no assigned workplace at all (so-called hot-desking). Again, while these changes may in general be positively perceived by information workers, they also contribute to the increase of communication load, information fragmentation, and the growing diversity of digital tools and devices. Incompatibilities between different document formats, between and even within the same tools, also contribute to these challenges and increase fragmentation.

In this situation, supporting document and task management of information workers has become extremely important. As information in a modern office is to a large

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extent handled digitally, and, in addition, in many office settings the use of paper is restricted (for example, in clean desk settings or in hot-desking settings where people have no assigned workplace and only limited storage space), digital tools for supporting personal document and task management are becoming an absolute necessity. For designing such tools, understanding the needs of information workers and supporting the way users currently work is extremely important.

Tasks, Documents, and Personal Document-Management Systems

To outline the area in which digital tools for supporting personal document and task management are applicable, we will first discuss the notions of *task*, *document*, and *document-management* system in the context of the information worker's environment.

A *task* can be defined as an action or a series of actions towards some well-defined end, i.e., a change of state (Jones, 2007). Jones also proposed the notion of "projects," representing high-level goals (e.g., buy a house) consisting of several subprojects and tasks, execution of which is necessary to complete the project. In the field of personal information management (PIM), which addresses the support of information workers, the definition of a task coined by Bellotti et al. (2004) is widely accepted. The authors proposed a view of the task as "something that one can put on a to-do list." Naturally, the entries on a to-do list can represent various levels of abstraction, from higher-level activities (e.g., work on a presentation) to more specific actions (e.g., schedule a date for the presentation).

Identifying tasks on varying levels of abstraction may be explained by action identification theory (Vallacher & Wegner, 1987). This theory suggests that the same set of actions can be cognitively viewed from different perspectives by different actors, depending on the complexity of the actions, the context, and the actor's experience. Sequences of actions that are often repeated become automated and can be executed subconsciously. This allows an actor to move to a higher level of identification (e.g., "getting home" instead of "driving a car") and to free up cognitive resources for more abstract levels of activity. An experienced actor, therefore, executes the set of automated chunks from the lower levels while keeping only the higher-level goal actively in mind. Driving a car can be one of the examples of automated chunks: An inexperienced driver has to think about every action, however, over time the pressing of pedals and shifting of gears do not require attention anymore.

To support information workers it is important to understand the nature of their tasks and the structure of their workflow. The fundamental difference between manual work and knowledge work has influenced our understanding of the structure of an information worker's tasks. For example, assembling a car is, to a manual worker, a preplanned set of activities hierarchically decomposed into subtasks, specified by someone else in order to get to a prespecified result. Compare this to a routine task of an information worker, such as writing a report, consisting of a succession of largely unpredictable steps and getting to a result with few predefined requirements. Drucker (1999) suggested that the key factor of productive knowledge work is the autonomy of the worker, in particular, in identifying his or her tasks. "Knowledge work, unlike manual work, does not program the worker" (Drucker, p. 85). Information workers, therefore, are to a large extent free to define the way they achieve their goals and accordingly the structure of their task flow. This results in an unstructured and unpredictable workflow, where the notion of task is vaguely identified (Kirsh, 2000).

The definition of a *task* of an information worker can therefore be extended by relying on the information worker to identify which action or series of actions towards some well-defined end or change of state he or she considers to be a task, depending on his or her context, experience, and the complexity of the required actions.

The tasks of information workers are often initiated by documents, such as e-mail messages with requests, articles with new ideas, or memos with questions. The outcome of these tasks is, in turn, also most often expressed in the form of documents. Documents, therefore, are an integral part of an information worker's task flow. Despite the term *document* being widely used in everyday language as well as in scientific literature, it "has resisted easy definition" (Jones, 2007, p. 36). The complex relationship between the notion of information and the ways of communicating it has led to broad definitions such as "any expression of human thought" (Buckland, 1997, p. 805) or even the identification of *any* object as a document—provided that by observation of such object people are being informed (Otlet, 1934). These broad definitions, however, also include objects such as an antelope in a zoo (Briet, 1951/2006) or archaeological finds (Otlet) as documents, although they normally would not have been considered as such (at least not in the context of an office environment). Further, these definitions would have been difficult, if not impossible, to use for practical purposes, such as designing a system for managing documents.

Buckland (1997) has provided a comprehensive overview of the discussion around the definition of a document and suggested that digital technology has introduced new challenges for defining a document, as previous materialistic definitions would have to be reviewed to incorporate notions of a digital document. Buckland (1991) also introduced the concept of "information-as-thing," which has recently been further elaborated by Jones (2007). Jones proposed the term *information item* for a tangible representation of a "package" (container) of information, such as a paper document or an e-mail message, or a small information scrap such as a note. This definition is well suited to use for developing system requirements and for design. Although Jones distinguished between documents and other information items such as Web pages, depending on the degree to which one can manipulate them, these differences between types of information items are quickly blurring (Karger, 2007). For example, one can print a Web page or save it locally thus changing the ways

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it can be manipulated. Hence, in this work, the conventional term *document* will be used for any information item that information workers may possibly use to perform their tasks.

The close relationship between tasks and documents of information workers (Belotti, et al., 2004; Bondarenko & Janssen, 2005), which will be discussed further later in this article, suggests that document and task management have to be considered as two integral parts of one process—managing tasks and related documents—rather than two separate processes. An information worker executes subjectively defined tasks, as discussed above, and uses documents along the way to perform these tasks. The task is at the core of the process, while various kinds of documents are used as means to complete the task, independent of their origin. Thus, in the context of the office environment, document- and task-management processes acquire a personal perspective, as opposed to company-wide centralized document- or task-management processes. Although the latter is already well supported by digital systems, personal document management has only recently acquired the attention of researchers and designers of document-management systems. The new domain of personal information management has emerged, relevant studies from which will be discussed in the Related Work section of this article. Still, a digital system that supports personal document and task management as an integral process, independent of the level on which tasks are defined by the information worker and including all documents that are required to complete a task, is still to be designed. In this article we intend to bring such a system one step closer to implementation by systematically summarizing the findings of research into personal document and task management of information workers and deriving requirements for system design.

Understanding Document and Task Management Needs of Information Workers

In a series of three studies on document and task management of information workers, which will be briefly summarized below, we have been aiming to understand the current needs of information workers, focusing on those needs that are at this time best supported by paper-document management. In this article we summarize the findings of these three studies in the form of a series of requirements for the design of a personal document management system (DMS).

First study. In Bondarenko and Janssen (2005) we found that task-relevant collections of paper documents reflect a person's task flow and reveal the current state of his or her tasks at a given moment. This is one of the reasons why information workers keep actively using task-related collections of paper documents in this digital era. Based on the results of contextual interviews, artifact walkthroughs, and critical-incident collection, we concluded that by putting task-related documents together, information workers are able to create a representation of a "stable state" within a task. For instance, a pile of documents is frequently manipulated during a task; the results of these manipulations remain visible and in turn represent the actual state of the task. As such, the organization of documents helps the worker to resume a task after an interruption, which is almost inevitable in a multitasking environment.

Second study. In Bondarenko (2006) we concluded that the manipulation of paper documents plays an important role in creating a stable state at the moment of switching between tasks. Based on the results of detailed participant observation we identified eight task-switching patterns, which varied in how explicitly the task state was encoded in the environment and in how actively the subject was encoding the task state at the moment of switching. The reason for the switch (self-switching or external interruption) had an effect on the occurrence of active manipulation of documents during task switching. Whereas self-switching resulted in active document manipulation, subjects did not actively manipulate their task-related document collections in order to preserve the state of the task when switching due to external interruptions. The domain where the last action was performed also had an influence on the switching pattern, with active manipulation of documents occurring more often in the physical domain. These findings illustrate that the physical and digital environment have different affordances to support task switching and task management.

Third study. In Bondarenko and Janssen (2009) we started from the hypothesis that paper documents possess visually distinctive attributes that are associated with the semantics of related tasks. By manipulating task-related documents at the moment of task switching, these visually distinctive attributes change, reflecting the changes in the task state accordingly. Based on a highly structured interview technique (a combination of triad elicitation and laddering) we were able to develop a model of relationships between the identified visual cues of paper documents and semantic judgments of the task. These relationships could be interpreted based on content dependency, flexibility, and effort, which together define ease of manipulation. We therefore concluded that the physical environment and, in particular, task-relevant paper documents, allow flexible encoding of task-related semantic cues into available environmental visual cues.

A Framework for Understanding Document- and Task-Management Needs

As mentioned before, in this paper the findings of the above three studies in the form of requirements for the design of a DMS will be summarized. To this end we propose a framework, based on task-decomposition layers, which helps to understand the needs of information workers with regard to document and task management (see Table 1).

The framework is directly based on the results of the aforementioned research studies and was derived as follows. Three researchers (all with relevant expertise in the field of personal information management) performed a qualitative analysis

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TABLE 1. Four layers of task decomposition, supported user processes, and corresponding requirements.

Task decomposition level	Supported process	Requirements
Knowledge work	Document and task management	Support least-effort principle: Document and task management are secondary tasks for an information worker
Unstructured workflow	Nondeterministic task flow	Support unstructured workflow with ad hoc collections of associated documents: Documents are representations of tasks
Multitasking	Frequent switching	Support representing the current state of the task in the environment: Tasks are most often switched without finishing up
Task suspension and resumption	Stable state creation	Support encoding of semantic information about the task state into easily available and flexible visual cues: Cues encode the state of suspended tasks

of the research findings using the affinity-diagram technique (Hackos & Redish, 1998). The analysis consisted of two stages. During the first stage the researchers independently reviewed the main research findings presented in Bondarenko and Janssen (2005), Bondarenko (2006), and Bondarenko and Janssen (2009) and marked all parts that they considered relevant for DMS design requirements (including the user processes to be supported) on Post-it notes. During the second stage, a joint interpretation session was organized where they iteratively grouped the Post-it notes into clusters, proposed names for the clusters, and arranged the named clusters into a framework. The task-decomposition framework shown in Table 1 arose after only a few minor changes in this original framework.

Each of the layers shown in Table 1 has important implications for the requirements for a digital system that is aimed to support document management. First, the nature of the knowledge work that is performed by information workers has implications for the design of a document- and task-management system. Document and task management are important parts of the activities of an information worker; however, they are not the worker's primary activity. In this layer, therefore, the support of the "least-effort principle" is important to maintain, as will be discussed in detail in the section on requirements for Layer 1. Second, knowledge work (in part) is performed in an unstructured workflow, which requires support for an erratic, nondeterministic task flow. Documents of information workers are closely related to corresponding tasks, and therefore a DMS should provide support for task management with ad hoc collections of task-associated documents, which will be discussed in detail in the section on requirements for Layer 2. Third, multitasking is an inherent part of the aforementioned unstructured workflow. Multitasking results in frequent task switching, which often occurs in an unpredictable manner. When switching between tasks, information workers need a representation of the task state of an unfinished task in the environment. For a further discussion see the section on requirements for Layer 3. Finally, frequent suspension of the current task in the environment and resumption of previously postponed tasks is required for performing within the aforementioned multitasking environment. As our latest study shows (Bondarenko & Janssen, 2009), information workers actively use their physical environment to encode information about the state of their suspended tasks to free up cognitive resources for the following task execution. Ways to transfer the support for this process into a DMS are discussed in the section on requirements for Layer 4.

Related Work

The expansion of personal information management studies in the past several years has resulted, on the one hand, in an increasing number of research studies investigating current user needs and practices (e.g., Barreau & Nardi, 1995; Czerwinski, Horvitz, & Wilhite, 2004; Gonzàlez & Mark, 2004; Kidd, 1994), and, on the other hand, to the development of various prototypes for digital systems supporting PIM (e.g., Cutrell, Robbins, Dumais, & Sarin, 2006; Fertig, Freeman, & Gelernter, 1996; Karger & Quan, 2004; Morteo, Gonzàlez, Favela, & Mark, 2004). Both directions have contributed to understanding the needs of information workers in document and task management. However, there are limitations to both approaches. First, studies into current practices and needs often summarize these needs without deriving requirements that can be applied by system designers. Second, publications on prototyped systems often concentrate on the details of system design and evaluation rather than on presenting the underlying requirements so that these can be reused by others. This makes it difficult to compare different systems and build upon previous work and to preserve the continuity of research. Deriving requirements that can be used for the design of digital systems is therefore an important contribution to the development of the PIM field. Below we will focus on relevant requirements for a DMS that could be extracted from studies following both of the aforementioned approaches. Furthermore, throughout this paper we will provide a comparison with the resulting set of requirements derived from the results of the current research.

Providing Flexibility and Automation

It has been suggested that current designs of digital systems do not allow for sufficient flexibility with regard to information organization (Ravasio, Schär, & Krueger, 2004). Forced classification of documents along with explicit labeling, as is currently required when one wants to place a document into a digital system, has been compared to flexible

and ad hoc ways of organization, such as piling, possible when organizing paper documents (e.g., Kidd, 1994; Malone, 1983). Requirements for a DMS directed to replicate this natural flexibility of paper in document organization and retrieval have been formulated. For instance, Malone suggested supporting multiple document classifications and allowing classification without explicit labeling, whereas Kidd proposed supporting labeling things in a new way. Providing flexibility for attribute specification in a search system (Blanc-Brude & Scapin, 2007) and methods for document recovery, and supporting variation in user strategies by providing flexibility to manage different types of information in distinct ways (Boardman & Sasse, 2004) have been also suggested. In addition, it has been suggested that a DMS should also provide flexible views of resources (Mark, Gonzàlez, & Harris, 2005) and maintain a flexible window of focus among such resources (Gonzàlez & Mark, 2005). Flexibility of recording and organization, as well as supporting a variety of strategies, have been identified as especially crucial for dealing with information types that may often fall outside existing structures and categories, such as information scraps (Bernstein, Van Kleek, Karger, & Schraefel, 2008).

It has also been suggested that excessive automation of document-organization processes should be avoided because of the difficulty of predicting user actions on information or interpreting its meaning (Kidd, 1994). Fully automated classification without user input should therefore be avoided (Whittaker & Sidner, 1996). We may, however, expect that a certain degree of automation in classification of documents may be useful for reducing user effort and for avoiding cluttering of information (Malone, 1983; Whittaker & Hirschberg, 2001). It has been repeatedly suggested that automatic classification of information, such as clustering related documents, should be based on the way the user interacts with these documents and should therefore change dynamically along with the usage (Teevan, Alvarado, Ackerman, & Karger, 2004; Whittaker & Sidner, 1996). Systems could also provide suggestions based on such automated processing, such as, for example, indicating changes in the value of information (Whittaker & Hirschberg, 2001) or indicating and adjusting priorities (Malone, 1983).

Mimicking Properties of the Physical Environment

The important role of the physical environment for document and task management of information workers has been noted and translated into requirements for digital systems. It has been suggested that digital systems should mimic and extend critical properties of the physical environment (Kidd, 1994; Whittaker & Hirschberg, 2001), such as reproducing the marks information workers put on documents, or allowing access to information based on spatial location (Malone, 1983). Visibility of documents, and as a consequence, the ability to supply visual reminders, have been identified as features that should be required to be transferred into a digital system in a number of studies (Bernstein et al., 2008; Czerwinski et al., 2004; Gonzàlez & Mark, 2004; Malone, 1983). This has been extended by more specific requirements, such as allowing the user to mark a document for action or program a reminder (Whittaker & Sidner, 1996). Another natural ability of physical document organization, namely providing an overview of one's documents and related activities, has been also proposed as a requirement for a digital system (Bellotti, Ducheneaut, Howard, & Smith, 2003; Czerwinski et al., 2004; Gonzàlez & Mark, 2005).

Supporting Task Management

The observed relationship between paper-document management and task management of information workers has led to requirements for a DMS to support task management (Whittaker & Sidner, 1996). To this end, it should be possible to create task-centric collections of documents and extend them with task-relevant information, such as reminders or required actions (Bellotti et al., 2003; Czerwinski et al., 2004). Another requirement relevant for supporting task management is to preserve relationships between documents and collections, since from such relationships contextual information can be derived (Bernstein et al., 2008; Blanc-Brude & Scapin, 2007; Whittaker & Sidner, 1996). Switching between tasks has been identified as a crucial moment in a multitasking workflow that requires support by preserving the state of the system at the moment of interruption (Czerwinski et al., 2004; Mark et al., 2005; Morteo et al., 2004).

Integration Between Document Origins and Tools

At the moment, documents of information workers are distributed over various domains (physical, digital) and places (local, such as hard drive or mailbox, but also remote, such as network storage or Internet). This distribution, on the one hand, increases information fragmentation, but on the other hand, the document's origin provides important contextual information to the user and hence should be preserved (Teevan et al., 2004). The system should therefore not enforce unnecessary integration between tools (Boardman & Sasse, 2004). At the moment the task is performed, however, task-relevant documents need to be gathered in one place (Karger, 2007), which also supports task resumption (Morteo et al., 2004). The need for a unified document-management approach has also been discussed, along with the necessity to preserve information about document origin and format, as they signal important elements of a document's context (Jones, 2007). Finally, it has been suggested that a DMS should integrate with other systems such as a file system or e-mail operations (Cutrell et al., 2006).

Requirements for a Personal Document Management System

In the following sections we will review each layer of the framework presented in Table 1, elaborating on related needs and suggesting a set of requirements for digital support of the corresponding user processes. Our aim is to propose a comprehensive view of an information worker's document

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and task management and to derive requirements for efficient digital support of personal document and task management. We will detail the above-mentioned layers, provide associated requirements for a personal document management system, and review the advantages and shortcomings observed for paper-based document-management practices.

Layer 1: Supporting Task Management in Knowledge Work

Though documents are an essential part of every task of information workers, and often also the end product of these tasks, managing documents is by itself not part of the primary processes within knowledge work. With some exceptions, such as personal assistants, secretaries, or dedicated document-management workers (e.g., librarians), for most information workers document management is a secondary, background process beyond their primary tasks. In his classic paper about the productivity of knowledge work, Drucker (1999) emphasized that activities outside the primary tasks of knowledge workers have to be reduced in order to increase their productivity. Learning and maintaining a DMS may often be perceived as a burden by information workers who as a consequence are not willing to invest much effort into these activities. An effort-demanding document-management system can therefore be expected to have a negative influence on productivity. To minimize this, the system should meet the following requirement:

> *Requirement 1.* A document-management system should require as little effort as possible to set up and maintain in order not to take time or mental effort that should be devoted to primary tasks (least-effort principle)

This requirement is essential for a successful DMS. As we discussed in Bondarenko and Janssen (2005), the effort that information workers are willing to invest into managing their documents is often limited. Hectic workflows and increasing performance demands leave little time for those activities that do not belong to primary tasks. There are always other, more important things to do than filing outdated documents or cleaning up a mailbox. A DMS that requires effort or time that is actually needed for performing primary tasks will as a result negatively influence performance. An example of such effort is requiring labeling and explicit categorization of each and every document that goes into the system, which is inherent to the traditional file-management system (e.g., Microsoft Windows). It is known that knowledge workers have difficulty categorizing documents due to the unpredictability of their workflow (Kidd, 1994). Studies show that in systems that do not require categorization, many documents remain uncategorized over long periods of time (Boardman & Sasse, 2004). Yet, every document that is created or saved in a file system needs to be named and positioned at a certain place within a folder hierarchy. This is a substantial effort especially for those documents that were not previously categorized and do not possess any implied categorization criteria, for example, an article that has not yet been read. The need to avoid explicit categorization and to allow flexible labeling of documents has been also suggested before (Bernstein et al., 2008; Kidd, 1994; Malone, 1983). A few other examples of processes that can require excessive effort are manually filling in metadata about documents (such as topic, keywords, or summary), learning and maintaining a new document-management system, version management, and manual synchronization between various storage locations.

To satisfy the least-effort principle, the following two requirements have to be met: The system has to be based on system(s) already in use, and the system has to support a variety of existing styles and ways of working.

> *Requirement 1A.* The system should be based on system(s) in use.

As discussed above, information workers have to deal with various document sources: their own file systems, e-mails, corporate DMS, intranet, Internet, and so forth. Typically, these sources have different physical and syntactic formats, which makes transitions between these sources difficult and leads to information fragmentation. Information fragmentation has been recognized as a major problem in the PIM field (Jones, 2007). Some researchers have therefore proposed dedicated solutions for document management that integrate documents from different sources into a single system (e.g., Karger & Quan, 2004; Morteo et al., 2004). Introducing a dedicated tool for document management, however, will in the end only add to the effort required for managing documents, as the user will have yet another system to maintain. As long as the system is unable to incorporate and fully integrate all kinds of digital documents, or requires frequent user input to do so, it becomes a burden for the user and may potentially increase information fragmentation. We can therefore expect that the resulting increase of fragmentation and extra required maintenance will overcome any benefits that the system could possibly offer.

It may be concluded that extending an existing personal DMS, which is already in use, with support for task management, will increase the performance of information workers. E-mail has been proposed several times as the basis for such an integrated DMS that could also support task management (Bellotti et al., 2003; Kerr & Wilcox, 2004). Current e-mail clients such as Microsoft Outlook 2007 have indeed to some extent incorporated task-management functionality, for example, mechanisms to relate task entries to relevant e-mail messages and calendar entries. This functionality is, however, severely limited, as other documents, such as those stored in a file system, or elsewhere, cannot be merged into this system. Furthermore, as suggested in earlier studies (Whittaker & Sidner, 1996), the current "e-mail overload" and the focus of e-mail on communication may prevent e-mail from functioning successfully as a unified DMS. Instead, more fundamental support on the level of the operating system may be required for developing a successful DMS.

> *Requirement 1B.* The system should support a variety of existing ways of organizing documents and tasks, rather than imposing its own.

The ways information workers manage tasks and documents vary significantly depending on a range of factors: individual preferences, personality traits (Malone, 1983), type of work (Bondarenko & Janssen, 2005), organizational policies, and so on. For example, for administrative workers, who follow predefined procedures and have well-structured workflows, it may be easier to categorize documents according to a strict hierarchical system, whereas a researcher may find it difficult to categorize documents as the unpredictable workflow requires ad hoc categorization (Bondarenko & Janssen, 2005). Another example of the varieties in document organization strategies is related to personality traits. Filers are expected to prefer arranging documents in ordered groups, whereas pilers may prefer to leave their documents unarranged (Whittaker & Hirschberg, 2001). Combinations of all these factors result in an wide array of variations in document management styles, making them practically unique for every individual. Our research shows that information workers often fall somewhere in between the filer and piler extremes, performing a mix of structured and unstructured activities (Bondarenko & Janssen, 2005). Supporting only one of the extremes, as the hierarchical file system does for filers and administrative workers, will increase the effort and time required for document management for the rest of the users. Notwithstanding the possibility that people might learn other, perhaps more effective styles of document management, an important requirement for the success of a DMS is that it should provide support for varied styles of document management.

Advantages of paper-based document-management practices: Paper unifies document sources and supports all styles and ways of working. Our research suggests that paper documents in the physical environment allow for the unification of sources and support a variety of work styles and personal preferences (Bondarenko & Janssen, 2005). This research showed that bringing documents together from different sources, fully supported only on paper, is one of the major reasons for printing digital documents. In addition, handling paper documents allows for a variety of organizational styles that support different personal preferences and ways of working. For example, pilers may pile up their papers or spread them around their desks; filers, in turn, can organize paper using a variety of office tools available today. Paper also supports "transitional" states (e.g., partly structured collections) and changes in state (e.g., "shuffling" a well-arranged document collection). Digital systems, even those that allow for less rigid organizations (such as e-mail programs), do not support such variety; for example, they do not allow for partly structured collections or gradual changes in state. Although the maintenance of collections of paper documents can become quite demanding, the initial effort is rather low (a document can just be put "somewhere" on the desk) and categorization or filing can be postponed until a convenient moment. Paper, therefore, allows for combining documents from any source together and supports a variety of document management styles—thereby complying with the least-effort principle.

Shortcomings of paper-based document-management practices: Paper increases information fragmentation and does not support refinding. As most documents are now available digitally, paper document collections have acquired a secondary role, becoming the mirror of their digital analogues and thus contributing to the fragmentation of information in the office. Constant switching between the physical and digital environment requires a significant effort due to the fundamental differences in interaction mechanisms. Besides that, paper and digital collections can hardly be synchronized, which increases information fragmentation. In addition, digital systems support refinding, which may be necessary for large or infrequently used collections, with a number of integrated mechanisms, such as automatic rearrangement according to predefined criteria (e.g., sorting by attributes) or keyword-based search.

Layer 2: Supporting a Nondeterministic Task Flow

Multiple research studies have shown that multitasking in an unstructured workflow has become routine for information workers (Czerwinski et al., 2004; Mark et al., 2005). These studies also showed unexpectedly small time intervals for performing a task; multiple tasks often had to be performed simultaneously. Information workers, therefore, have to constantly juggle their tasks and priorities, often in an unpredictable manner. Gonzàlez and Mark (2005) identified three fundamental processes related to task management in an unstructured workflow. First, renewing the overview of "working spheres" (tasks in their broader context) is required to maintain the overview of tasks and actions and to identify priorities. Second, strategizing how to manage transitions between contexts is important for smooth switching between tasks. Third, maintaining a flexible focus between different working spheres is necessary as an erratic workflow may cause a sudden change of priorities that should not be overlooked. It was observed that task-related documents play an important role in supporting these processes. Following these findings and extending them with a detailed understanding of task-switching patterns (Bondarenko, 2006), we conclude that a DMS should meet the following requirement:

> *Requirement 2.* A document-management system should support task management in an unstructured workflow by providing ad hoc collections of task-related documents as a representation of tasks.

As mentioned above, tasks of information workers are frequently built around documents. Accordingly, document collections are often arranged according to tasks, especially when documents from various sources need to be combined for the purposes of task execution. For example, preparing a report may involve external documents (e.g., articles downloaded from the Internet or intranet), different versions of

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the report itself, created by the user and stored on the hard drive, e-mail messages from coauthors, handwritten notes from meetings, and so forth. While the task is ongoing, a convenient way to combine relevant documents is to print them and put them together in a pile on the desk, updating the pile as the task goes on. To support this process in a digital system, the following requirement should be satisfied:

Requirement 2A. The system should allow arrangement of documents/collections of documents along with the task flow and provide an overview of task-related collections.

A collection of documents, such as the "report" pile mentioned in the example above, is a representation of a task ("preparing a report"), and it is created and frequently changed during task execution. Tasks are complex notions that reside in the minds of information workers and can partly be externalized into the environment, for example, in the form of entries on a to-do list, but also as collections of documents, such as the aforementioned report pile. The structure and content of this pile preserve information about the task that will be discussed in detail in the section on requirements for Layer 4. Hence, the physical environment allows having documents related to the task and providing information about the task at hand whenever they are needed (Bondarenko & Janssen, 2005). A DMS, therefore, should preferably be task-oriented, allowing task notions to emerge from collections of documents. Some recent versions of digital systems, such as Microsoft Outlook 2007, made a step in this direction by letting the user put an e-mail message as a task entry on a to-do list. As tasks often emerge from e-mail messages, this is a reasonable choice: Information provided in the message gives the context for the entry on the to-do list, which represents a task. As the task develops, however, more documents, such as reports, presentation, Web pages, get involved. These documents are left outside the context of an e-mail–related task entry and therefore have to be arranged elsewhere. The user has to rely on his or her memory to access these documents and relate them to the to-do item. As a result, task-relevant documents, including the initial e-mail, have a good chance of being printed out and ending up on one's desk, whereas the to-do item in Outlook serves only as a reminder.

The aforementioned mechanism, however, partly satisfies the next requirement: Representation of a task in the digital environment should emerge from a (collection of) relevant document(s) rather than from a manual entry in a dedicated task-management system, which requires an explicit effort for creating and updating the task entry. To support this need, the following requirements should be met:

Requirement 2A1. The system should allow task-relevant representations across collections of documents.

For example, it should be possible to arrange task-relevant documents from different sources as one task-related collection. Stated the other way around, a task-related view should be possible on a type-related collection of documents, such as e-mail messages, as well as across various document sources. Again, Microsoft Outlook 2007 allows the user to label the messages with custom-created nonexclusive categories and retrieve a collection of messages by category, which may then be task related. This mechanism, however, requires significant user effort for creating and maintaining a category system, involving a rather cumbersome multistep interactive process, and is therefore only suitable for organizing long-term high-level activities, rather than rapidly changing tasks. In addition, it is limited to e-mail messages only, as discussed above.

As Gonzàlez and Mark (2005) stipulated, information workers require a constantly updated overview of their tasks. Research showed that an office desk, displaying task-related document collections, often serves as a representation of such an overview (Bondarenko & Janssen, 2005). Especially at the moment of task switching, an overview of pending tasks to review the priorities is required. To transfer this mechanism to the digital domain, the system should satisfy the following requirements:

Requirement 2A2. The system should provide an overview of task-related document collections reflecting their state without additional interaction by the user.

We have already stressed the importance of the relationship between tasks and related documents. This relationship is important to preserve in a DMS. The overview of tasks should contain not only the list of pending tasks (i.e., a "to-do list") but also provide context information about the state of the tasks through the view on relevant document collections. The properties of the task state should then emerge from the attributes belonging to such a collection, rather than being manually entered by the user, as will be suggested in the section on requirements for Layer 4. Whereas it is possible to have an overview of task entries in a task list (e.g., in Microsoft Outlook), the list of tasks remains out of context if separated from other task-related documents. Information about the actual task state is in this case missing.

Requirement 2B. The system should allow implicit planning/prioritizing among tasks or task-related document collections.

The relationships between tasks, changes in planning, and priorities should also be made visible in relation to document collections that belong to the tasks. The system should provide unobtrusive reminders about the status of pending tasks, which has also been suggested in earlier studies (Czerwinski et al., 2004; Gonzàlez & Mark, 2004; Malone, 1983). The mechanisms currently available in the digital domain to support this requirement have limited functionality, and reminders provided by most systems are implemented as a combination of pop-up messages and auditory alerts, which are obtrusive for the user.

Advantages of paper-based document-management practices: One's desk provides a constant overview of tasks, at a glance and with unobtrusive reminders. A desk with paper document collections provides an overview of one's tasks. Postponing tasks or changing priorities can be directly reflected in the physical environment, for example, by changing the location of task-relevant collections of documents, without additional effort. Visual attributes of paper documents provide clues about the actual state of the task, which helps to identify priorities within a task flow. In addition, documents placed within one's area of attention serve as unobtrusive reminders about the corresponding tasks.

Shortcomings of paper-based document-management practices: Paper is passive and stable, and the physical environment is easily overloaded as the number of tasks increases; paper document collections become quickly outdated. The physical environment has its natural spatial limits. With increasing information flow and communication speed, more and more desks end up covered with mountains of paper, where the aforementioned advantages of paper disappear. In addition, most of the work-related communication between information workers, as well as the creation and review of information, currently occurs in the digital domain. When documents are transferred to the physical domain, they become disconnected from their digital "originals" as paper and digital copies cannot easily be synchronized. The fast flow of information and tasks complicates the maintenance of up-to-date paper document collections. For someone who has to perform a number of tasks a day involving close cooperation with other people, printing task-related documents may sometimes make no sense, as they immediately become outdated. These factors stimulate the need for adequate digital document-management support according to the requirements described above.

Layer 3: Supporting Frequent Task Switching as a Result of Multitasking

Multitasking and the increasing pace of work result in frequent task switching. On average, people switch to another task every 11 minutes (Gonzàlez & Mark, 2004). Task switching may be caused by external interruptions, often unexpected, or initiated by the information workers themselves. Whatever the reason, the moment of switching is a crucial point in the workflow when the current task is suspended and the next task is chosen and resumed. As people most often have to switch before completing the task, they have to preserve the state of the task in order to resume it later on. To support this process, a DMS has to satisfy the following requirements:

> *Requirement 3.* The system should support task suspension and resumption in the environment.

There is a natural background mechanism for such support, as task execution most of the time results in changes in the environment and, in particular, in changes in the documents that belong to the task. Writing a report, annotating an article, or e-mailing a colleague all leave traces in the environment that reflect the actual state of the task (e.g., the annotations on the article show how far one was in reviewing it, the position of the cursor on the screen indicates where one was typing, etc.). At the moment of unexpected task switching, such as an external interruption, the traces of the previous task may remain in the environment and provide useful information about the task state upon resumption. To support this process a DMS should satisfy the following requirement:

> *Requirement 3A.* The system should support preserving the current state of environment, reflecting the task state.

Our research shows that at the moment of external interruptions information workers often prefer not to actively manipulate their documents in order to preserve the state of an interrupted task (Bondarenko, 2006). Instead, their attention is directed at the source of the interruption. Traces of the task progress (such as open documents on the screen and papers on the desk) remain in the environment and will help to resume the task after the interruption (Czerwinski et al., 2004). These traces are, however, fragile, since interruption may require the use of the same environment, such as changing the layout or content of the windows on the screen. A system may preserve these traces, by, for example, maintaining the layout of the windows and their content at the moment of interruptions (Czerwinski et al., 2004; Morteo et al., 2004).

Preserving traces of the task as they are (e.g., layout of windows) will, however, only help to resume the task on a short notice. This information is insufficient for long-term preservations as the meaning of such implicit cues will fade from memory. This suggests that history-based DMS's, where documents are automatically arranged according to the history of their usage (for example Lifestreams; see Fertig et al., 1996) may not be sufficient for preserving the state of the task for a longer period. The user, therefore, should have the opportunity to actively manipulate information about the task state at the moments of self-switching in order to preserve the state of the task in a meaningful manner. To support this process, the following requirement should be satisfied:

> *Requirement 3B.* The system should allow custom changes in the representation of the current state of the task.

Our research shows that information workers purposely manipulate their physical environment and rearrange their documents at moments of self-initiated task switching (Bondarenko, 2006). This process allows a tradeoff between resources that the user is willing to spend (such as time and mental effort required for rearranging document collections) and quality of task-state preservation (e.g., how easy it will be to resume the task in the future). This process is directed at long-term preservation of information about the task state to support resuming the task later on.

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Advantages of paper-based document-management practices: The state of the task is more robust in the physical environment; physical space allows for simultaneous representation of a number of tasks. The physical environment immediately reflects changes in ongoing tasks and represents the current state of the task at any given moment. Changes made in the physical domain are often of a more robust nature than in the digital domain. For example, whereas annotations on digital documents will often be discarded automatically unless explicitly saved (thus not involving an explicit action from the user) an annotation, once made on a piece of paper, will require an explicit action to be removed. The state of the task in the physical environment is therefore preserved more easily at the moment of an unexpected task switch. The digital domain introduces a fundamentally different paradigm, requiring a confirmation for preserving changes in a document, such as saving a file before closing it. In addition, the behavior differs by system (for example, some software tools save a document automatically after a certain period of time without requiring user confirmation, whereas others do not), hence system behavior becomes unpredictable for the user. The physical environment also allows for simultaneous representation of multiple task-related document collections, limited only by the size of one's workplace. This reduces the risk of destroying the representation of the interrupted task state by activities related to the interrupting task.

Shortcomings of paper-based document-management practices: Paper always requires an action. Observing the task-suspension process of information workers, we concluded that in the digital domain there is often no action required at the end of the task in order to finish it (Bondarenko, 2006). One may think of pressing the *send* button on an e-mail message window, or typing another Web address in a Web browser window. In other cases, suspending the task can be done with no effort by the user, such as pressing the *close* button of a document window. This allows instantaneous switching to the next task. Suspending interaction with physical objects, in contrast, always requires an action (e.g., a book has to be closed and put aside, a document in hand has to be placed somewhere on the desk). On the one hand, this mechanism can be an advantage, as it enables task traces to always be available in the environment, as described above. On the other hand, this requires active interaction from the user, when attention may be already directed elsewhere (such as in the case of an unexpected interruption) or preservation of the task state may not be required. In this case, due to the limitations of physical space, it may quickly become cluttered with unnecessary traces, such as outdated reminders or wrongly placed documents.

Layer 4: Supporting Task Suspension and Resumption by Encoding the Task State in the Environment

Due to frequent task switching, information workers have to suspend and resume their tasks often. Offloading part of the knowledge about the task state into the environment allows freeing up memory and cognitive resources for the next task. It has been observed that information workers actively manipulate their physical environment at the moment of task switching: rearranging documents, adjusting piles, and throwing away outdated information (Bondarenko, 2006). This is an implicit, often subconscious process; a typical example is when someone pushes aside a document that does not need immediate attention. In a recent study we suggested that visual cues residing in the environment (such as spatial location) are related to semantic judgments about the state of a task, such as whether it requires an action (Bondarenko & Janssen, 2009). For example, environmental cues such as location (distance to the center of attention, relation to specific objects) were found to be related to semantic judgments of planning and overview (whether a task requires an action or not, whether it has been recently or frequently accessed). An empirical model of such relationships between visual cues of paper documents and semantic judgments of tasks was proposed. The requirements described in this section are based on this model (for detailed discussion of the model, see Bondarenko & Janssen, 2009).

We concluded that visual cues in the physical environment play an important role in document- and task-management processes. Many of these visual cues, however, cannot be transferred from the physical to the digital environment directly due to fundamental differences between these environments. For example, there is no direct digital analogue for spatial location with regard to one's center of attention (such as the space around one's keyboard on a physical desk) in a digital system, as most of the time the screen is occupied with the window that is currently active. This makes implicit planning based on location cues, such as pushing a document away, impossible. In the digital environment, however, other types of cues are available that can serve to encode the same semantic judgments. We therefore argue that a digital system should not attempt to mimic visual cues from the physical domain, as suggested earlier (Kidd, 1994; Whittaker & Hirschberg, 2001). Instead, the system should satisfy the following requirement:

> *Requirement 4.* The system should support encoding of semantic judgments related to the task state in cues available in the digital domain.

For a successful DMS the mechanism of establishing relationships between environmental cues and semantic judgments should be provided. From the model of the relationships between cues in the physical environment and semantic judgments (Bondarenko & Janssen, 2009), a number of important relationships emerged that are translated in this section into requirements for a DMS. The following key aspects of the mechanism of encoding are addressed:

- Providing information about the past: extraction
- Providing extracted information on the proper granularity level
- Encoding information about the future and higher-level concepts: allowing user input
- Encoding information of a proper level

Providing information about the past: Extraction. Our research shows that users of paper documents associate information about past usage with visual cues these documents provide. This information may concern the use of the document (e.g., what kind of interaction it allows, what types of information it contains), the owner or intended audience (is it for the worker's own use or is it meant to be presented to others?), and period or frequency of use. Relevant visual cues in the physical domain include appearance of the content of the document, group arrangement of documents, and location.

The digital domain has a number of advantages compared to the physical environment. One of them is that metadata, or information about document attributes (in particular, its past usage) can be automatically recorded, extracted, and displayed without requiring user input. This approach satisfies the least-effort principle and corresponds to earlier findings suggesting that automation based on document usage can be helpful for digital-document organization (Malone, 1983; Teevan et al., 2004; Whittaker & Hirschberg, 2001; Whittaker & Sidner, 1996).

Some information that is already available at the system level relates directly to the semantic judgments discussed above, and therefore it only needs to be extracted and visualized. In this way, instead of providing visual cues and letting the user encode semantic information, the system can provide information directly relevant for semantic judgments. To this end, the following requirement should be satisfied:

> *Requirement 4A.* Extract and visualize relevant semantic data about a document's usage, such as
>
> 1. Interaction possibilities (what can be done with a document)
> 2. Information presentation (what kind of information does a document contain)
> 3. Ownership of a document (mainly on a "mine" vs. "not mine" level)
> 4. Intended audience (is a document meant for the worker's own use or to be presented to others?)
> 5. Period of use (short vs. long term)
> 6. Frequency of use (frequently vs. rarely used).

Providing extracted information on the proper granularity level. The aforementioned information not only needs to be extracted; it also needs to be presented in an appropriate way in the digital domain. An important aspect is the level of detail of the presented information. Currently, in the digital domain information is often presented the way it is extracted, and therefore, precisely: the exact size of a file in bytes, the time of creation up to the minute, and so forth. Moreover, the measurement units are often system-specific and not user-specific (e.g., size of a file in bytes instead of number of pages in a document). Norman (1988) suggested that people do not need information on a too detailed level, and Blanc-Brude and Scapin (2007) demonstrated that too-detailed information (e.g., the size of a file in bytes) is not well recalled by users. In contrast, in the physical domain information encoded in visual cues is less precise, and choosing the level of detail is up to the user. For example, when visually comparing the size of a pile of documents to a single document there is no need to know exactly how many pages each of them contains. Therefore, in the digital domain, information should be presented on the users' level and in meaningful units. For example, the frequency of use in the physical domain was mainly described by our participants as daily versus weekly or monthly (Bondarenko & Janssen, 2009). A digital system may also leave the level of detail to be customized by the user, or allow zooming up to the exact detail. This aspect is often already taken into account in modern retrieval systems that employ user-specific terms (e.g., "yesterday" instead of an exact date, "large" instead of an exact size) or in e-mail clients that sort e-mail messages by relative time period instead of exact dates. This should however be expanded to the other system functions relevant for the organization of documents. The following requirement should therefore be satisfied:

> *Requirement 4B.* The system should provide extracted information on a granularity level required by the user and in user-specified terms, and allow customization of the level of granularity.

Advantages of paper-based document-management practices: Much of the semantic information about the task state is speculation of the user based on available environmental cues. We are all "forensic experts" of our desks. Researchers in personal information management often refer to anecdotal examples of extreme pilers claiming they can find the way through their desks easily and in no time. A possible explanation for this phenomenon is the aforementioned flexibility of relationships between visual cues and semantic judgments in the physical world, as well as the richness of available cues. For example, recognizing one's own handwriting on a document makes one believe that the document is made by oneself while it also signals an unfinished task in progress. A page full of text is perceived as requiring reading, whereas an empty page calls for writing. Hereby the affordances of paper play a defining role, allowing for deriving task-relevant information without much cognitive effort. Spatial location is another important visual cue that is difficult to transfer literally to the digital domain due to the limitations of space on the screen. The most frequently or recently used documents end up closer to the center of attention, whereas documents related to postponed activities are pushed away to the edges of the desk. The aforementioned visual cues can be perceived and processed "in the background" of the user's mind without requiring much cognitive effort (at least, compared to the effort required for recognizing and interpreting the last date of use of a file, or the name of the author).

Shortcomings of paper-based document-management practices: Visual cues are highly implicit. Visual cues, as discussed above, are highly implicit in the physical domain and most of them can only be interpreted by the owner of the document (e.g., you may recognize your own handwriting but often not your colleague's). First, this makes it impossible to reuse the same cues in a system that is meant for the use by more than one user; desks of other people provide much less

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information about their owners' task flow than your own. Second, as most semantic information resides in the user's mind, it may eventually fade from memory, especially when more specific information is required. For example, it is impossible to identify from the location of a document the exact time period when it was last used.

Encoding information about the future and higher level concepts: Allowing user input. Some information about the document or the task it belongs to, concerning higher-level semantic concepts (such as importance or confidentiality) or future use (e.g., if an action is still required), was also found to be related to the visual cues in the physical environment. Importance and required action are often represented by location, so that the documents for which an action is required are placed in the center of attention (e.g., next to the keyboard), whereas important documents have a special location (e.g., next to the telephone). Confidentiality is often represented by manipulating the visibility of content (confidential documents are put face down or folded). In the digital domain, such information requires explicit user input, as a digital system cannot define higher-level concepts or future use automatically (Kidd, 1994). A DMS should therefore satisfy the following requirement:

> *Requirement 4C.* The system should allow the user to indicate and change higher-level concepts and information about future use for task-related documents or document collections, such as (a) importance, (b) confidentiality, and (c) action demand.

Finding a way to indicate higher-level concepts, such as importance or confidentiality, is still challenging in the digital domain. Some mechanisms, however, are already available or have been adopted by users. E-mailing a message to oneself, flagging an e-mail message or marking it as unread, putting a file on the desktop or creating a to-do folder and placing documents in there that require an action, are some of the strategies that people already use to indicate an action that has to be taken or the importance of a document in the digital domain. Interestingly, in these mechanisms the visual modality, such as spotting a flag or a visually distinctive unread message, also plays an important role. The aforementioned actions often occur in an e-mail client for a number of reasons. First, the reminding signal (e.g., a flag) is attached to the message that contains information about the action that needs to be taken, and therefore remains within the task context. Second, reminders stay at hand, because information workers often keep the e-mail client open and return to it multiple times through the day (Bellotti et al., 2003). Third, Web access to e-mail offers the possibility of working in different locations and still having access to the reminders.

Encoding information of a proper level. For many ongoing tasks, part of the information about the task state is encoded in the physical environment. Most of the information about the task, however, remains in the user's mind. On the one hand, offloading all information about the task into the environment would cost much effort, as the user would have to make all details about the task explicit (for example, by writing down all information about the task). On the other hand, it is often not necessary to offload all information about the task into the environment, as the user only needs some cues to retrieve the rest of the information from memory (such as a short Post-it note attached to the monitor). Belotti et al. (2004) also confirmed that to-do items are often short and highly implicit, rather than providing extensive information about a task.

Digital document-management and task-management systems, in contrast, often demand input of explicit and precise information about the task: exact dates of deadlines, time for a reminder, names of participants, topics of meetings, and so forth. Entering this information into a system and keeping it up to date conflicts with the least-effort principle. Even such if information is available without user input, when provided, it requires an extra effort from the user to be recognized and interpreted.

Keeping a balance between knowledge in the world and knowledge in the head (Norman, 1988) is therefore an important factor for a DMS. Such a balance may depend on individual preferences and on specific tasks. Our research shows that sometimes people do make an explicit note with how to proceed with a task, whereas most often rearranging documents is enough, and most of the task information remains in the user's mind (Bondarenko, 2006). For example, it may be necessary to specify the exact starting time of an important meeting. However, time may become redundant information for a nonurgent, routine task that has to be performed "somewhere during the day."

The willingness of the user to offload explicit information about the task (and accordingly to increase the effort needed for task suspension) may depend on the relationship between the costs of externalizing this information versus the risk of it disappearing from memory. This is why names and contact information are found to be one of the most frequently occurring information types recorded in the form of information scraps (Bernstein et al., 2008).

The following requirement should therefore be satisfied:

> *Requirement 4D.* The system should be adaptable with regard to the user effort required for offloading and uploading information about task state to and from the environment. Only the needed information should be requested and later presented.

Advantages of paper-based document-management practices: The physical domain allows workers to flexibly assign semantic judgments to available environmental cues on a user-specified level. The physical environment is sufficiently flexible to allow attaching conceptual semantic judgments to the available cues. The users set it up for their convenience: Documents that need action are put in a place where they are immediately visible, important documents get a distinctive location to avoid losing them, confidential documents are put out of sight. The visual cues can be easily changed or updated if necessary (e.g., when the document does not need an action anymore it can be put out of sight).

At the same time, one can offload to the physical domain information in as much detail as desired, from putting a document in the center of the desk (thus indicating that something has to be done with it) to writing down an elaborate note of what kind of action is required.

Shortcomings of paper-based document-management practices: The implicitness of cues prevents long-term planning. Unlike in the physical domain, where changing location is almost effortless but bears meaning, in the digital domain the user has to put a lot of effort into setting up a reminder. Yet, as physical objects are passive, a reminder can often be lost or overlooked. In the physical domain, therefore, dedicated tools are often used for long-term planning, such as a paper calendar. These tools require frequent consultation and must be updated manually. A digital system can be proactive in giving a signal or initiating an action that would otherwise be forgotten. It can also be updated automatically, thus avoiding unnecessary user effort. A digital reminder, therefore, can be more productive than a physical one, because it can attract one's attention at the predefined moment and be suspended after a predefined period of time, and has fewer chances to be overlooked than a Post-it note on the desk. A DMS that satisfies requirements presented in this article may therefore be more suitable for encoding information about future task-related activities.

Discussion

Our research has focused on the relation between personal document management and task management; the requirements presented in this article are therefore directed to support this relation, and thus pertain to the management of current documents ("hot" and "warm," as defined by Sellen & Harper, 2002) rather than to the organization, long-term storage, and retrieval of archived ("cold") documents. As discussed in the Introduction of this paper, retrieval systems, irrespective of their quality, cannot substitute for a document-management system that supports the organization of current documents. First, current documents are well-remembered because they are actively in use and therefore do not require searching (Barreau & Nardi, 1995). Second, the organization of current documents is a task-related process that therefore follows the context of a task; in contrast, the retrieval of digital documents often relies on the attributes of a specific document (e.g., size, modification date) rather than on task-relevant context. Throughout this article we referred to relevant studies where requirements for a DMS were presented, focusing on those requirements applicable for management of actual documents. In this section we will highlight the most prominent findings and outline implications for the design of a digital DM system.

One of the most important system requirements coming out of this research is the necessity for any DMS to comply with the least-effort principle. Document and task management are of crucial importance for the successful performance of information workers. Our research showed that successful performance in the hectic multitasking environment of modern offices requires efficient manipulation of task-relevant documents at hand, along with managing changes in the task flow. However, the more tasks an information worker has to perform simultaneously, the more effort a document- or task-management system requires in order to be up-to-date and to support task switching, and the less time and mental capacity this information worker has available for investing in such a system. Systems conforming to the least-effort principle are therefore to be preferred when supporting the management of documents and tasks. The design of such systems should therefore be carefully evaluated from the perspective of how much (perceived) user effort is required to operate them, rather than only focusing on the functionality itself.

When we employ the term *user effort* we refer both to ease of use (i.e., ease of interaction with a system interface) and to the mental effort that is required from the user to operate the system. For example, it might be easy to create a folder and to store a document in it from the point of view of interaction; however, the mental effort required for explicit labeling and categorization cannot be reduced by interaction mechanisms. Incorporating mechanisms for encoding semantic judgments into digitally available cues is necessary to reduce the mental effort that is currently required, as current cues often require verbalization for offloading information about the task. As discussed in the previous section, much information about the task that is required for preserving the task state is already available in the digital domain without requiring user input. Providing this information at the proper moment and in the proper way can be a significant contribution to the support of document and task management of the information worker in a way that cannot be achieved by a paper-based system.

Paper-based document- and task-management strategies satisfy the least-effort principle due to the flexibility of paper-document organization and the low initial effort required for creating and maintaining task-relevant document collections. But the increased speed of communication, along with the fact that most documents are currently created and distributed through digital channels, make paper-based systems insufficient. Still, when transferring the advantages of paper to the digital domain, one has to keep in mind that a DMS should not require more effort than a paper-based system, independent of its potential benefits.

Digital systems often implement flexibility in the form of deliberate choices that the user has to make while operating the system. The necessity of making a deliberate choice increases the required effort without always offering a corresponding benefit. First, Hyman (1953) has shown that reaction time increases monotonically with the provided number of alternatives. The number of choices that the user has to make, such as, for example, choosing a particular format for saving a document, will therefore contribute to the user effort. Second, the provided alternatives need to be interpreted before a choice can be made. This interpretation also requires effort; especially when the consequences of the choices are unclear, this produces uncertainty that complicates decision making. Third, the choices that the user has to

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make, and their consequences for the user's workflow, often bear little relation to the user's expectation for the corresponding benefit. For example, saving a brief note to oneself, one that may be discarded on the same day, requires the same effort as filing a final copy of a report about a project that has been going on for years. The user may become reluctant to invest effort into a digital system when he or she does not see a corresponding benefit. In contrast, managing paper documents allows for many different cost/benefit tradeoffs, with an increase in effort generally corresponding to an increase in the subjectively perceived benefit. In addition, the consequences of the chosen strategy are more apparent. For example, one may expect that placing a document in an arbitrary location on the desk will be less suitable for a robust long-term preservation of this document than filing it in an appropriate folder together with other relevant documents. One can therefore easily choose a preferred strategy depending on the desired benefit.

It would be incorrect to state that the physical environment allows for a completely effortless organization of documents. Although the initial effort of putting a document "somewhere" on the desk is rather low, elaborate collections of labeled folders and subfolders exist in the paper domain as well. Moreover, it can cost even more effort to create and maintain such a collection in the physical domain than in the digital domain; yet information workers create and maintain such collections. These collections, however, mostly contain "cold" documents that need to be preserved for later use. The actual documents that are on people's desks usually represent a variety of organizational structures, with some collections being more organized than others. The fundamental properties of the physical domain allow for such variety, because these properties can be gradually changed. For example, one paper pile may be more shuffled than another; the orientation of a document can be somewhat misaligned with regard to the desk, and so forth. The physical domain therefore supports a range of document-management strategies that gradually change from sticking a Post-it note somewhere on the desk, to putting documents on top of each other in a pile, up to creating a well-structured archive. In contrast, the digital domain mainly supports the well-structured extreme, with very limited possibilities for quick and ad hoc structuring. Requirement 1B, supporting a variety of document-management strategies, is therefore of critical importance for a DMS, to allow the user to be in control of the amount of effort he or she is willing to put into creating and maintaining a document collection.

Throughout this article we illustrated our requirements with examples of popular systems that are currently used by information workers for document and task management purposes, such as Microsoft Outlook 2007. Our main goal was to provide specific examples for better understanding the requirements. We wish to point out here that mechanisms such as hierarchical structuring and explicit labeling of objects are at the core of current digital systems. The effort that the user has to put into creating and maintaining a collection of digital documents is therefore to a large extent predefined. On the one hand, these mechanisms will remain a bottleneck for the successful support of document and task management of information workers since they are contradictory to the cognitive processes that have to be supported by the system (such as recognition versus recall: recognizing a paper document by its visual appearance compared to recalling a file name or other text-based attributes of a digital document). On the other hand, adapting to a fundamentally different design of digital systems, such as an essentially different operating system, or a dedicated DMS, will also require an enormous effort on the part of the user. As Jones, Phuwanartnurak, Gill, and Bruce (2005) showed, people don't want their folders to be "taken away" because they have gotten used to them already. We may therefore expect that adaptation of system design will have to be performed iteratively to allow users to adapt their digital document-management strategies gradually.

Conclusions

In this article we summarized the results of three studies in current document-management practices of information workers. We proposed a comprehensive framework based on layers of task decomposition, identified related user processes at each layer, and presented requirements for the design of a personal document- and task-management system accordingly. First, document and task management is a secondary, supportive process within knowledge work. A DMS therefore has to satisfy the least-effort principle in order to facilitate performance of information workers. Second, the unstructured workflow, almost inevitable in knowledge work, requires supporting task management by enabling task-relevant document collections. Third, frequent and unpredictable task switching, as a result of multitasking in an unstructured workflow, requires representing the current state of the task in the environment. Finally, encoding semantic judgments in available environmental cues is required in order to support task suspension and resumption when frequently switching between tasks.

We have identified the least-effort principle as an essential requirement to be satisfied by a document-management system. Our research suggests that the flexibility of paper, frequently mentioned as a major advantage compared to digital-document organization, is mainly related to the well-balanced cost/benefit trade-off of physical-document organization. Organizing paper documents allows users to choose a level of effort that they are willing to invest that is proportional to the expected benefit. The physical environment allows for a large variety of such choices with regard to document organization, with required effort gradually changing and consequences of the choices being clear. In contrast, digital systems are less flexible and often require the user to invest an effort into document organization without taking into account the proportional relationship of such effort to the potential benefits.

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